Development of high performance grouts for post-tensioned tendons and ground anchors

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DEVELOPMENT OF HIGH PERFORMANCE GROUTS FOR POST-TENSIONED TENDONS AND GROUND ANCHORS

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Abstract: *The presented results are part of the COST 534 group project "Improvement of properties of grouts for prestressing tendons and/or ground anchors", which is dealing with the rheology of grouts and with the improvement of grout performance for prestressing tendons and ground anchors. Common procedures for testing the rheology, setting times, bleeding and volume change of grouts as well as new developed methods for testing grouts have been used in this project. Results of the influence of ingredients - cement and admixtures - on the parameters required in standards and guidelines are reported and the pros and cons of the reqiurements are discussed. Test methods and evaluation criteria are discussed and it will be shown that some of the prescribed test methods and requirements are not representative enough.*

1. INTRODUCTION

Portland cement grout is used in post-tensioned and retaining structures to provide bond between the tendon/anchor and the surrounding concrete/ground and to ensure durable structures. The space between the steel and surrounding material (duct, rock, etc.) should be fully filled with grout, creating physical barriers, and ensuring corrosion protection for the tendons and ground anchors. Grout for bonded post-tensioning is a combination of portland cement and water, along with different admixtures needed to obtain required properties. An optimum grout combines desirable fresh and hardened properties, together with good corrosion protection.
The existing European Standards EN 445 and 447 "Grout for prestressing tendons" as well as the *fib*-guideline "Grouting of tendons in prestressed concrete" give general guidance and define test procedures for quality control of grouts, but there is no guidance for grout formulation. Therefore research work on the influence of different admixtures on physical and mechanical grout properties for the application in post-tensioned structures and in ground strengthening with anchors has been conducted with the overall goal to develop rules for grout formulation. Besides influences such as particle size distribution or the chemistry of the cement and aggregates, grouts may contain several admixtures such as a plasticizer, an expanding and gas entraining agent, etc., which can influence the properties of the fresh grouts. Important properties are rheology, stability of the suspension with respect to bleeding and settlement, setting times, expansion, mechanical strength, bond strength and permeability. The investigations are part of the European COST Materials Action 534 "New Materials and Systems for Prestressed Concrete Structures" and are carried out within group project "Improvement of properties of grouts for prestressing tendons and/or ground anchors", under direct cooperation between three institutes from Austria, Croatia and Scotland.

2. TEST PROGRAMME AND MATERIALS

Within the project previously mentioned, research work on rheology, volume change, bleeding, etc. of different grout mixtures has been performed. The grouts tested were cement/water mixtures prepared without or with the addition of admixtures such as a superplasticizer, a retarder, an expanding material or commercially available products sold for grout preparation which contain all necessary ingredients. The w/c-ratio was 0.40 and the admixtures were formally considered as aggregates. All types of admixtures were obtained from selected producers. Cements from Austria, Croatia and the UK were used (CEM I; CEM II-AS, CEM II B-S and CEM II F-S). In addition one commercially available grout, ready for mixing with water, was included in the tests. The investigations reported here included the following tests:

- Determination of rheological parameters and their time dependent changes of grout prepared without and with the addition of admixtures
- Volume change
- Bleeding
- Setting times

3. RHEOLOGY

Fluidity test as required in the standards should provide information on the rheological behaviour of the grout. However, rheology is clearly a complex property and can not be adequately determined by a single point measurement such as the cone test according EN 445:1996[1]. Therefore, beside fluidity tests according EN 445:1996 rheology tests were carried out with the use of a scientific instrument.

3.1 Fluidity tests according EN 445:1996

For determination of grout fluidity, the flow cone test method was used, where grout is poured in the cone (1,7 litre of volume), and then the time until the 1 litre of grout flows out is measured. The time is measured immediately after all ingredients have been mixed and after 30 minutes of mixing, and it should be less then 25 seconds according to EN 447:1996[1].

3.1.1 Results of testing

The series of testing on 40 different grout mixtures had been performed[2], from which here are presented selected results. Water/cement ratio was 0.40 in most cases, and the influence of different admixtures was determined. Superplasticizers Glenium 51, Viscocrete 20 HE and Viscocrete 5-800, then expansive additive Intraplast, Stabilmac, Flowcable and Injektin; and retarder Intracrete, and Silica Fume were used for the grout mixture preparation. Two types of cement were used: (1) CEM II/A-S 42,5N and (2) CEM I 42,5R. In table 1 is given the overview of grout mixtures and their results of fluidity testing.

Table 1. Results of fluidity test

#	*w/c*	*CEM.*	**ADMIXTURE (%, w/w cement)**	***FLUIDITY (s)***
1	0,40	1	-	170 / 420
2	0,44	1	-	34 / 40
3	0,40	1	1% INTRAPLAST	38 / 24,5
4	0,40	1	0,20% GLENIUM 51	24 / 24
5	0,40	1	0,20% GLENIUM 51; 0,75 % STABILMAC	15 / 22
6	0,40	1	0,20% GLENIUM 51; 1,2 % STABILMAC	16,5 / 16
7	0,40	2	0,20% GLENIUM 51; 0,50% FLOWCABLE	43,5 / 53,9
8	0,40	1	0,50% VISCOCRETE 20 HE; 5% SILICA FUME	34 / 44
9	0,40	1	0,35% VISCOCRETE 5-800	16,5 / 20
10	0,40	2	1% INTRAPLAST; 2% INTRACRETE	20,3 / 21
11	0,40	2	0,5% INJEKTIN	19,5 / 26

3.1.2. Discussion on results

From the table 1, it is obvious that grout produced only from cement and water doesn't satisfy the requirement of fluidity, even at the maximum allowed water/cement-ratio according European Standards of 0.44. With the addition of superplasticizers the requirement of fluidity was fully satisfied, while this was not always the case when other admixtures (expansive agent; retarder) were added. Silica Fume decreased fluidity additionally.

3.2 Tests of rheology

3.2.1 Sample preparation

All cement pastes containing an admixture were prepared with a w/c-ratio of 0.40. Only for measuring the effect of w/c-ratio one sample of each cement was prepared with a w/c-ratio of 0.50, too, but without any admixture. The recipe for w/c-ratio 0.40 was 200g cement, 80g distilled water and the necessary quantity of the respective admixture which was considered as an aggregate even if it was an aqueous solution. First, the admixture (± 1 mg) was put into the container used for mixing and the mixing water was added. The cement was added after its complete dissolution and mixing was performed manually with a spoon.
The rheological tests were carried out using a coaxial instrument (figure 1). The cement paste to be tested was filled into an outer cylinder (usually a vessel made of stainless steel) and an inner cylinder immersing in the paste. After starting a test, the cylinder begins to rotate at a speed which was preset in the computer. The resistance of the paste against shearing depends on its viscosity and causes a shear stress or a torque which is measured. Only cylinders with a smooth surface are commercially available as rotating bodies but when a suspension like a cement paste is tested, there is a risk of sedimentation and of water film formation at the surface of cylinder, and consequently of underestimating the shear stress. Therefore, after preliminary measurements an impeller (figure 1) was used to avoid such separation effects, as suggested by Banfill et al[4,5]. Figure 2 shows the test program used. Each test was started exactly 5 minutes after the addition of the cement to the water. At the beginning there was a pre-shear period of 5 minutes at a shear rate of 250/s. This is useful in the case of cement in order to break down the existing internal structure due to formed agglomerates, etc. Then the measurement started beginning at a shear rate of practically zero. In the first stage, the shear rate was increased in 10 steps of a measurement time of 45 seconds each up to a shear rate of 10/s (R-1; R: ramp) and then, in a second ramp in 9 steps of 45 seconds each from 20/s to 200/s (R 2) and after this in the same way back to zero (Ramps 3 and 4). Therefore one cycle (indicated by step in the figure 2) was completed after 23 minutes. Six equal steps were measured within one test and therefore the whole test was completed after 138 minutes.

Figure 1. Rheomat with impeller

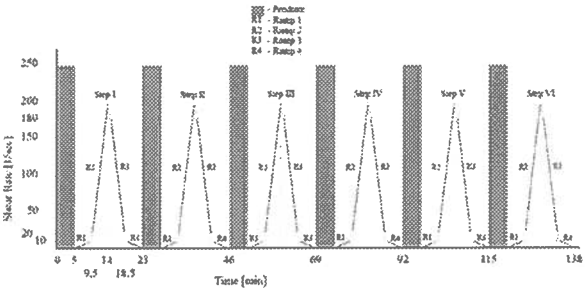

Figure 2. Test program

3.2.2 Results and discussion

Figures 3 and 4 show selected results of the rheology tests with the shear stress versus shear rate. To make it easier to compare the results only the curves of the first and of the last of the 6 measurement steps are shown. The increase of the shear stress from the 1st cycle to the last one indicates that a structure was formed in the cement paste with the time. As it can be seen from comparison of curves in figure 3, the addition of 0.3% of the superplasticizer Glenium 51 (polycarboxylate based) caused a remarkable decrease of the shear stress values which were very low even at the end of the test.

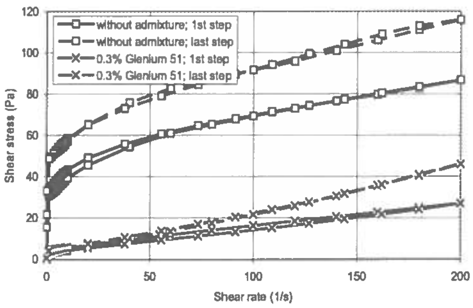

Figure 3. Flow curves of cement pastes (w/c-ratio 0.40) prepared without and with the addition of 0.3% (ww cement) of an superplasticizer

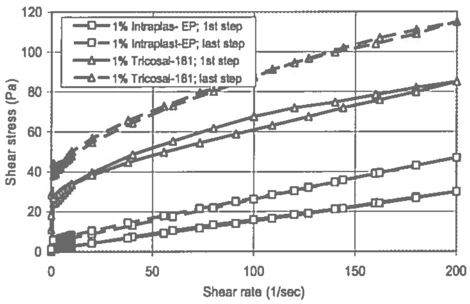

Figure 4. Flow curves of cement pastes (w/c-ratio 0.40) prepared with different commercially available products for grout preparation

Figure 4 shows that the two commercially available products (Intraplast EP and Tricosal-181) containing all necessary ingredients for grout preparation behaved rather differently. The rheological behaviour of Intraplast-EP was equally good as that of the grout containing 0.3% of a Glenium 51 (curve in figure 3), whereas Tricosal-181 showed hardly any difference from that of the paste prepared without any admixture. This shows that tests will be necessary before applying them in practice.

It should be noted that pre-shearing caused a breakdown of agglomerates so that the curves start at a shear stress of practically zero (this can not easily be seen from the diagrams). However, when the shear rates returned to about zero at the end of one step, the shear stress remained at values which can be seen on the ordinate. This means that a cement pastes, which would have flow curve as one in figure 3 "without admixture" or "Tricosal-181" in figure 4, should be mixed continuously, or i.e. breaks during grouting procedure should be avoided. Otherwise there is a risk that the yield stress makes difficult or impossible to start the movement of the grout again. Such effects can not or not clearly be read out from the fluidity test according EN 445:1996, since only 2 measurement values must be carried out, after mixing and 30 minutes later. During that time grout should be continuously agitated according chapter 6 "Batching and mixing" of the standard.[1]

All this makes clear that the information content of a flow curve is much higher than that of the fluidity test.

4. VOLUME CHANGE

4.1 Can method

According to the EN 445:1996 test procedure for volume change measurement prescribes either cylinder or can method. In the can method the volume difference is measured within 24 hours, meaning the height of grout in the can is measured immediately and 24 hours later. The limits are: 1% for shrinkage, 5% for expansion[1]. Results of tested grouts are given in table 2.

Table 2. Results of volume change measurements

#	*w/c*	*CEM.*	ADMIXTURE	VOLUME CHANGE (%)
1	0,40	1	-	-5,0
2	0,44	1	-	-5,6
3	0,40	1	1% INTRAPLAST	0,9
4	0,40	1	0,20% GLENIUM 51	-3,5
5	0,40	1	0,20% GLENIUM 51; 0,75 % STABILMAC	-5,4
6	0,40	1	0,20% GLENIUM 51; 1,2 % STABILMAC	-2,9
7	0,40	2	0,20% GLENIUM 51; 0,50% FLOWCABLE	-6,9
8	0,40	1	0,50% VISCOCRETE 20 HE; 5% SILICA FUME	-3,2
9	0,40	1	0,35% VISCOCRETE 5-800	-5,0
10	0,40	2	1% INTRAPLAST; 2% INTRACRETE	+3,8
11	0,40	2	0,5% INJEKTIN	-1,1

4.1.1 Discussion on results

Results of volume change are showing great differences in results, strongly depending on added admixtures in the grout. The expansive admixture Intraplast has shown positive influence, while the other expansive didn't succeed the requirement. Different grouts' surfaces after 24 hours are shown on figure 5. Some of the admixtures are obviously not compatible to each other and more research on their mutual influence should be done. Shrinkage of grout is a great problem, which depends mainly on the type of cement, to some extent on the amount of water and the added admixture. In the real structures shrinkage is definitely smaller due to the presence of tendons, and the amount of grout within the duct cross section is much less then in this measuring method.

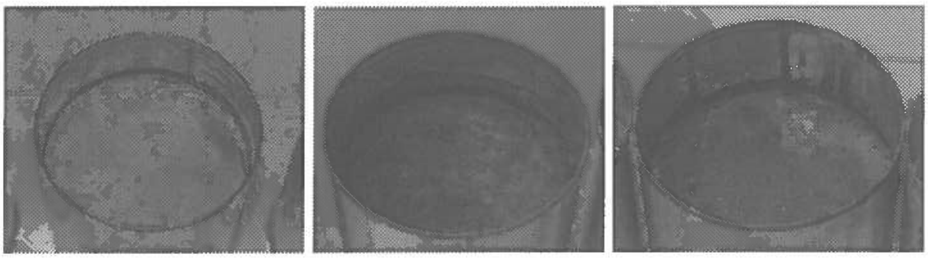

Figure 5. Different grouts after 24 hours

With the method according to EN 445:1996 the volume change of grout within the time is not determined, although it is important to know how long and how fast the volume is changing, in order to get the information about the volume change of grout after the injection. This measuring is though prescribed in the *fib*-guideline and the prEN 447, which contain the following note: "The purpose of recording at intervals instead of simply taking the final value is to be able to follow the behaviour of expansive grouts. If for one reason or another, the grout has been left for a time before being poured into the tube, expansion may be completed and measured value will be affected." [6,7]

4.2 New developed method

From previously described results it is clear that expansion measurements within the time are important. Therefore these tests were carried out during this research project. Since Wick-induced test seemed to be undesirable for laboratory conditions[8], a new and more sensitive method was developed. As it was known that expansion of grouts is often created by the formation of gas, it was assumed that expansion will occur particularly at the beginning and that therefore the first two hours will be most important. The only disadvantage of this test method is that it has to be completed before setting of grout. The following procedure was developed:

A glass vessel as shown in figure 6 was used. It consisted of an Erlenmeyer flask with a neck on its side and a scaled 10 ml pipe on its top with a scaling of 0.02 ml per division mark. It was placed on a magnetic stirrer and the paste was stirred during the whole test or not at all. A tube was attached to the neck and a funnel on the free end of the tube. The cement paste was filled in until it reached the lower end of the scaling of the pipe, for which about 150 ml of cement paste was necessary. Then the tube was closed by a clamp and the funnel removed. Immediately after filling, the position of the paste on the scale was noted down. The measurements of the volume changes were tested every 10 minutes up to a total of 150 minutes.

As the ultimate goal of the project is to define rules for grout preparation and because the ingredients of the commercially available products are kept secret by the producers, it was necessary to find an agent causing expansion the fresh cement paste by gas development. It turned out that Azo-Dicarbonamide is suitable. This compound is sparingly soluble in neutral water but easily soluble in an alkaline aqueous solution. It decomposes slowly, forming ammonium gas (NH_3) and therefore causing expansion.

Figure 7 shows the results obtained at room temperature. As expected, the volume of the paste prepared without the addition of an additive decreased somewhat due to volume shrinkage of water during hydration (volume difference between free and chemically bound water). The volume of the pastes containing commercially available products for grout preparation showed the greatest expansion within 60 minutes (Intraplast EP; Tricosal 181; the addition of 1%, ww cement, is the quantity recommended by the producers). Expansion was more or less complete in case of Intraplast EP after this time but increased slowly in case of Tricosal 181 until the end of the measurement (150 minutes). The expansion agent Rheomac 803 showed a volume increase of only about 2.5 vol. % and its expansion was already completed after about 30 minutes. Several quantities of Azo-Dicarbonamide ($C_2H_4N_4O_2$) were tested and the results of two of them are shown in the figure 7. The addition of 0.1% by mass of cement showed a total expansion comparable to that of the products Intraplast EP and Tricosal 181 but the volume increased somewhat slower. After

50 minutes an increase of only about 3% was measured, whereas expansion was about 4% in case of Intraplast EP and Tricosal 181. It was surprising to see that the commercially available grout SikaGrout 300PT showed practically neither expansion nor contraction. Obviously, expansion is not always considered to be necessary.

Figure 6. Measurement of volume change of a fresh cement paste

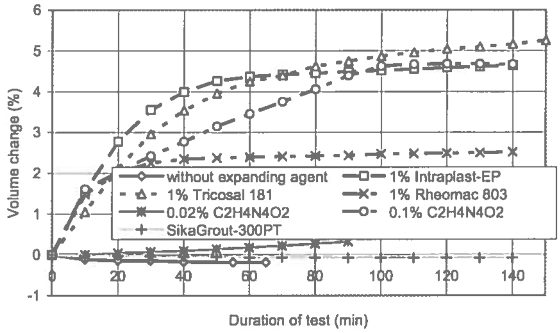

Figure 7. Volume change of cement pastes (w/c- ratio: 0.40) without and with the addition of expanding agents

The results show that different products behave rather differently, which is visible in total percentage of expansion and in the time during which expansion occurs. However, no respective information is contained on that in the product descriptions of the producers. Since it is important to know how long and how much grouts will expand under practical conditions, it seems to be necessary to test them before the usage.

4.3 Bleeding and setting

Bleeding tests were carried out according to EN 447:1996. As bleeding and setting is measured by the same method but at different times of reading (bleeding: 3 hours, volume change: 24 hours) the amount of bleeding water can easily be determined after 24 hours too.

Table 3. Results of bleeding tests

Binder	w/c-value	Admixture		Bleeding
		Name	Mass added (% of cem.)	(%)
CEM I	0,40	---	none	1.0
	0,60	---	none	2.0
CEM II B-S 32,5R	0,40	---	none	1,3
	0,50	---	none	2.3
	0,60	---	none	4.3
	0,40	Glenium 51	0,3	1.0
		Glenium C 323 Mix	0,6	0.3
		Melment F 10	0,6	0.7
		Viscocrete 5-000	0,3	0.3
		Sikament Multimix 200	1,0	0.7
		Glenium Sky 510	0,6	1.7
SikaGrout 300PT	0,40	---	none	1.3

The results show that all samples containing an admixture (5 different superplasticizers) met the requirement of EN 447:1996 and that the admixture can influence the bleeding behaviour. It should be mentioned that test results between the partners did not always correspond very well although they showed the same trends. The reasons are not yet clear and might be in connection with different materials having the same name, e.g. an admixture with the same name made by the same producer in different countries might behave a bit differently. Further, the bleeding values obtained by the glass cylinder method don't represent as already mentioned the true conditions inside the duct where bleeding values are much lower due to the presence of tendons.

4.4 Setting

The test was carried out according to EN 196-3. The water demand was determined with the admixture-free-paste of each cement and remained constant regardless the influence of the admixture. The results of the immersion test according to the named standard are given in table 4.

Table 4. Setting time

Cement	Admixture	Content of water (500 g cement)	Results of immersion test (mm)	Setting time (h:min) beginning	end
CEM I 42,5 R	not any	143	6	2:40	3:00
	1,0% Intraplast EP		0	6:45	7:20
	1,0% Tricosal 181		4	4:00	4:50
	0,5% Glenium 51		0	6:05	6:35
	1,0% Glenium C 323 Mix		0	5:45	6:10
	0,3% Melment F 10		0	5:05	5:40
	0,5% Viscocrete 5-000		0	5:35	6:00
	1,0% Glenium Sky 510		0	6:35	7:05

As it can be seen from the table 4, all pastes to which an admixture was added met the requirement for the beginning of setting according to prEN 447 and *fib*-guideline (>3 hours)[6,7]. The setting times obtained from pastes containing commercially available products for grout preparation (Intraplast EP and Tricosal 181) or a superplasticizer (the remaining five admixtures) were much longer than at the paste without any admixture. This shows that the addition of retarder as a special additive is not necessary for grout preparation.

6. SUMMARY AND CONCLUSIONS

The basic constituents of the high-performance grout are cement, water and admixtures, like stabilizing agents, expansive and plasticizer. Plasticizing admixtures reduce water demand while increasing flowability and reducing viscosity. Stabilizing agents reduce bleed, sedimentation, and segregation to produce a homogenous grout mix. These admixtures must be optimized for a given cement source.

Additional research is needed for defining compatibility of different admixtures, since there are some obvious changes of admixture functions when mixing together with another admixture.
Testing of the high-performance grout is necessary to determine suitability as well as for quality assurance/quality control in the field.

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